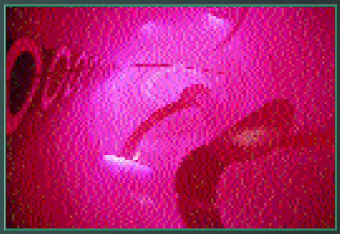
MANUFACTURING



Over the past decade, American manufacturing has made tremendous progress in improving the quality of products and services. The most successful U.S. manufacturers have realized that it is not what they produce but how well they produce it that determines customer satisfaction, sustained profitability, and long-term global competitiveness.

Advanced technology allows U.S. manufacturers to improve their techniques and processes and, in some cases, to reduce the environmental impact of manufacturing. For example, real-time computer software can help plant managers monitor and control processes remotely from multiple terminals, rather than limiting them to a single computer center at the plant site. In another example, new lead-free solder technology will enable manufacturers to produce stronger, more environmentally friendly printed circuit boards, which are used in nearly all electronic products.

Today's Market

Manufacturing is key to U.S. economic stability. Its share of the gross domestic product has remained remarkably stable, at 20 percent to 23 percent, for more than 45 years. Manufacturers employ 18.3 million people throughout the country. Thirty-seven states showed an increase in manufacturing jobs from 1993 to 1994. The United States is the world's largest industrial exporter. U.S. exports from 1985 to 1993 grew much faster than those of its two chief competitors, Japan and Germany.[1]

Tomorrow's Opportunity

BMDO has funded the development of advanced technology in pulsed power, control software, optical processing, and materials. While improving the Nation's defense, much of this technology also offers strategic benefits to the American manufacturing community, helping companies significantly improve their manufacturing capabilities. The following section describes seven of these innovations.

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[1]The Manufacturing Institute. The facts about modern manufacturing. World Wide Web at http://www.nam.org/Modern/FactsMan/summary.html.

Can You Imagine . . .

. . . a process that may be able to harden synthetic knee joints to make them last longer inside the body.

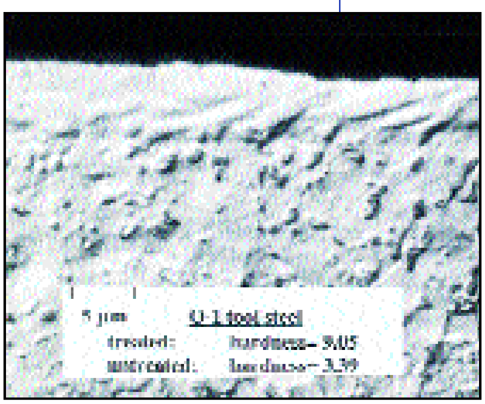
MATERIAL HARDENING PROCESS REDUCES TOOL-AND-DIE WEAR

For years, tool-and-die makers toughened their products using such processes as heat treatment and flame hardening. While these processes were highly effective, the growing demand for extreme precision in manufacturing new products made assembly lines and small precision fabrication shops much less tolerant of tool wear.

QM TECHNOLOGIES IS WORKING WITH MORE THAN A DOZEN COMPANIES TO VALIDATE INDUSTRY APPLICATIONS FOR IBEST℠ TECHNOLOGY.

Spinning off technology from Sandia National Laboratories (Albuquerque, NM), QM Technologies, Inc. (same location), licensed and markets a material-improvement technology called IBEST℠, or ion beam surface treatment. IBEST, an environmentally friendly pulsed ion beam process, can provide longer lasting, more wear- and corrosion-resistant materials for the tool-and-die industry, which the Association for Manufacturing Technology and the U.S. Department of Commerce estimated at $4.5 billion in 1994. BMDO-funded research in pulsed power technology enabled IBEST's development.

IBEST's benefits extend far beyond tools and dies. "Materials and surfaces are where everybody's problems are . . . everybody is up against the limit," comments Regan Stinnett of QM Technologies. Other industries, such as automotive and medical manufacturers, can also use IBEST for hardening materials. In the future, biomedical manufacturers may be able to use IBEST to treat synthetic knee joints (typically composed of a metal ball inside a plastic socket), which now have limited lifetimes inside the body. Treated knee joints would wear out less quickly, drastically reducing or eliminating replacement surgeries, which now typically occur every 7 to 10 years. QM Technologies is working with more than a dozen companies to validate industry applications of the technology.



■ This cross-sectional view of a steel tool sample shows the effects of rapid surface melting and cooling using IBEST℠ technology.

QM Technologies obtained the exclusive worldwide rights to the patented IBEST technology from Sandia National Laboratories. Through a Cooperative Research and Development Agreement with Sandia and ongoing relationships with Cornell University and Applied Pulsed Power, the company continues to develop IBEST technology. In addition, the Technology Venture Corporation, a nonprofit organization for commercializing technology from national laboratories and research universities in New Mexico, helped QM Technologies obtain over $4 million in venture capital from Rainbow Technologies Inc.

ABOUT THE TECHNOLOGY

IBEST uses high-energy, pulsed (typically less than 500 nanoseconds) ion beams to heat the surfaces of a material. Because of the pulsed nature of these beams and the rapid cooling rates of the surface-heated material, only very thin surface layers (2 to 20 microns) of the material are rapidly melted and cooled; this process helps form amorphous and nanocrystalline grain layers without altering the atomic composition of the material.

The Repetitive High-Energy Pulsed Power (RHEPP) accelerators deliver the unique combination of high average power and short-duration electrical pulses required for high-efficiency IBEST systems. A magnetically confined anode plasma (MAP) diode generates the short pulse of ions using the RHEPP accelerator power pulse. The electrical pulse, applied to a preionized gas in the MAP diode, extracts ions from the plasma. The ions then travel through a vacuum to the material surface. The IBEST ion beam cover areas up to 200 cm^2 with each pulse. The RHEPP I accelerator was initially developed for the Department of Energy's inertial confinement fusion experiments and BMDO's free-electron laser weapons system.

REAL-TIME SOFTWARE CONTROLS INDUSTRIAL PROCESSES

Can You Imagine . . .

. . . a software-based system that can monitor and control plant processes remotely from multiple terminals.

In light of environmental regulations and growing populations, upgrading or expanding waste and drinking water treatment plants has become a priority for many municipalities. Officials are plunging into several relatively high technology improvements, including more advanced computerized automation systems. Called supervisory control and data acquisition systems (SCADAs), this technology allows technicians and managers to monitor and control the newer, more sophisticated plant processes remotely from multiple terminals, rather than being limited to a single computer center at the plant site.

A notable example of this trend is the upgrade of a water treatment facility for the growing population of Las Vegas, Nevada. In this project, officials installed an advanced automation and control system called TIS 4000® derived from software used to control a BMDO-funded particle beam accelerator. Developed by Tate Integrated Systems (Owings Mills, MD), the software-based system combines the features of SCADAs with distributed control systems, so that plant technicians can monitor and control the various parameters of their water treatment systems in real time through graphical tools. For example, users can link a graphic of a water pump with a parameter such as flow, and then control that process.

TATE HAS FOUND SEVERAL MARKETS FOR ITS TIS 4000®, WITH $10 MILLION IN SALES SLATED FOR 1996 ALONE.

The TIS 4000's open architecture allows its use with a wide range of hardware. Through graphics, trend windows, and text, users see—and control—what is happening in their processes in real time. The system also features alarms that direct an operator to areas where problems occur.

Tate licensed the technology three years ago from both Los Alamos and Argonne National Laboratories (Livermore, CA, and Argonne, IL, respectively), tailoring it for municipal and industrial processes. The company found many uses for the product and expected $10 million in sales in 1996 alone. For example, Tate has installed TIS 4000 in Libby Owens Ford's new glass plant to automate and control the annealing stage of glass production. The company also sold the software for petrochemical uses for offshore oil production in the Arabian Gulf. The St. Louis County Water Authority uses TIS 4000 for its drinking water treatment facility, and Baltimore Gas and Electric uses it for its liquid natural gas terminal.

■ One of Tate's many applications for its TIS 4000® product is to automate and control oil production and distribution systems.

In addition to pursuing domestic markets, Tate sells its system abroad in such areas as Russia and South America. The company has established a joint venture in Malaysia to capture Southeast Asian markets.

Tate notes that the system can handle energy management in buildings. The product can control a building's heating, ventilating, and air conditioning systems to optimize and control energy usage and environmental conditions.

ABOUT THE TECHNOLOGY

TIS 4000 operates on a wide range of client hardware or on off-the-shelf equipment supplied by Tate and is simultaneously connected to both a local area network (LAN) and a wide area network. The standard system runs on commercially available workstations and bridges to networks of personal computers with minimal software modifications. A basic TIS 4000 system requires only a few building blocks (workstations, a LAN gateway, and remote terminal units or a process control unit), although larger systems are possible.

Can You Imagine . . .

. . . stronger, more fatigue-resistant solder technology that will help electronics manufacturers make miniature cellular phones and remote controls.

NEW SOLDER TECHNOLOGY WILL ENABLE SMALLER ELECTRONICS

The demand for miniature electronic devices grows year by year, and with it comes the need for smaller printed circuit boards (PCBs). These tiny PCBs have less space for solder connections, which must maintain the highest level of reliability.

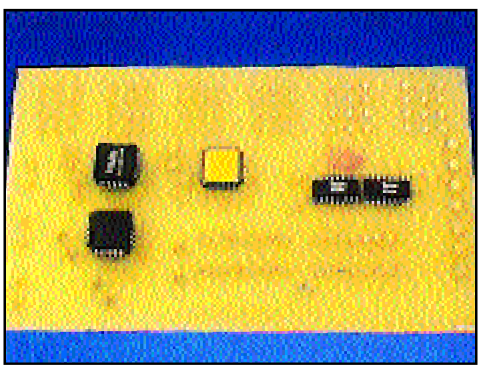
To avoid reliability problems, the BMDO SBIR program funded Toranaga Technologies, Inc. (Carlsbad, CA), to develop stronger, more fatigue-resistant solder technology for PCB manufacturing. Toranaga's proprietary combination of key metal alloys will make this grouping stronger than conventional lead-tin solders, allowing smaller, denser, and more rugged multilayer PCBs. BMDO needs more rugged PCBs for radar, missile interceptors, and other electronic equipment.

TORANAGA EXPECTS TO OFFER LICENSES FOR ITS LEAD-FREE ATTACHMENT TECHNOLOGY.

In addition, Toranaga's lead-free solder technology could alleviate growing environmental concerns over the disposal of lead-bearing PCBs, which can contaminate groundwater near landfills. Several European countries—including Germany, France, Sweden, and the United Kingdom—recently implemented mandatory recycling legislation for electronic components. These laws place the responsibility for proper disposal of lead-containing products squarely with the manufacturers. The adoption of similar waste disposal regulations in the United States would increase the domestic demand for lead-free solder technology.

Toranaga expects to license its solder to companies interested in creating lead-free attachment technology for their own electronic component assemblies. Its marketing department currently places the solder market at $350 million and growing 20 to 30 percent annually.

The company, formed to develop an organometallic conductive ink for creating wire traces on PCBs, entered into a licensing agreement with Kester Solder Company, a division of Litton Systems, to manufacture and market Ormet® ink. Kester provides royalty payments to Toranaga for transferring this technology to it.



■ This printed circuit board includes three types of components mounted with Toranaga's lead-free attachment technology.

ABOUT THE TECHNOLOGY

Investigating two solder products, Toranaga expects to meet the future demands of PCB assemblers using its atomized, lead-free alloy powders. The first product, a solder paste, will form stronger component joints than traditional lead-tin alloys. Because this formation will occur at a reflow temperature below 210°C, it represents a new solder option for PCB assembly. Most lead-free solder pastes require higher reflow temperatures, which can melt the plastic material of the PCB.

The second product combines a solder paste and a conductive adhesive. Designed to replace traditional solder pastes that lose mechanical bond strength because of accelerated aging, but similar to conventional solder, the hybrid will form strong intermetallic bonds with the contact pads. It will also form a metal matrix to stabilize electrical conduction within the joints, using a process called transient liquid-phase sintering. Finally, polymers in the hybrid will strengthen the joints. Toranaga expects the hybrid solder processing temperatures will be compatible with PCB manufacturing. Preliminary results from reliability testing show that the hybrid solder performs better than most commercially available conductive adhesives.

ENGINE PARTS GET BETTER COATINGS

Manufacturers seek quick and affordable methods to apply thin-film coatings on large or irregular surfaces. Typical coating methods, such as physical vapor deposition and thermal spray, deposit films unevenly on assembled parts because of the difficulty placing the parts inside a traditional coating chamber. In addition, thin films are costly for large surface areas in large-scale industrial settings. These barriers have been especially noticed in the high-volume U.S. automotive industry, which sold roughly 15 million motor vehicles in 1994 alone.[1]

Researchers at MicroCoating Technologies (Atlanta, GA) reduced the cost and increased the rate of thin-film deposition through a chamberless process called combustion chemical vapor deposition, or CCVD℠. Using this process, the researchers have been working with engine manufacturers to develop coatings for parts requiring catalytic surfaces as well as protection from heat, corrosion, and oxidation. They expect these efforts to improve engine performance and increase the lifetime and efficiency of automobiles.

CCVD is a flame-assisted process that deposits a wide spectrum of thin-film coatings in open atmosphere conditions. Unlike other low-cost deposition technologies, which produce low-quality coatings, this process can produce the same high-quality coatings as more expensive chemical and physical vapor deposition technologies. It also can coat objects that have large or irregular surfaces, such as engine parts, that are difficult to place inside a traditional coating chamber.

For example, CCVD deposits platinum, an excellent catalytic and corrosion-resistant element, evenly on the entire honeycomb structure of catalytic converters. Unlike other platinum-deposition methods, which may provide only partial coatings and require costly recoatings, CCVD would be a much more efficient alternative, saving car makers both time and money. The process can also deposit corrosion-resistant coatings onto many engine parts, including those used in automotive heating and cooling systems. Customers for these applications include General Motors/Delphi Automotive Systems, Caterpillar, and AlliedSignal.

Platinum CCVD coatings will soon be used for fiber-optic applications and are being considered for prototype fuel cell components. Funding from BMDO's SBIR program provided much of MicroCoating Technologies' startup capital and allowed the refinement of the CCVD process.

ABOUT THE TECHNOLOGY

In CCVD, a combustible liquid dissolves the chemical precursor. Then, combustion of the liquid atomizes the solution, forcing the reaction that results in deposition of the material on the substrate. Because the process is simple, deposition of multiple materials and complex compounds proceeds with few complications. CCVD also allows greater control of the physical structure of the coating.

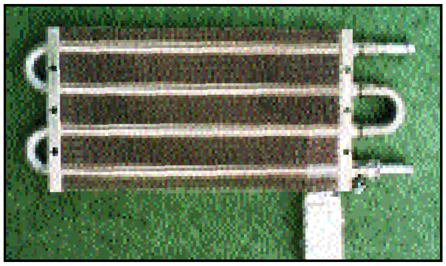
Because the CCVD process takes place at ambient temperatures, without a costly reaction furnace or vacuum chamber, technicians can continuously feed materials into the deposition zone, providing significant cost advantages over traditional thin-film processes. CCVD also uses inexpensive chemical solutions, or precursors, costing up to 100 times less than the high-purity, high-vapor-pressure solutions used in conventional chemical vapor deposition chambers.

[1]Standard and Poor's. 1995. *Industry Surveys*. 27 April, A-82.

Can You Imagine . . .

. . . a chemical vapor deposition process that coats objects, such as engine parts, that are generally difficult to place inside a traditional coating chamber.

SOME OF MICROCOATING TECHNOLOGIES' CUSTOMERS INCLUDE GENERAL MOTORS/ DELPHI AUTOMOTIVE SYSTEMS, CATERPILLAR, AND ALLIEDSIGNAL.



■ Pictured above is an aluminum radiator coated with platinum using MicroCoating Technologies' CCVD℠ process.

Can You Imagine . . .

. . . an optical processor that is at home on the factory floor and in the cell biology laboratory.

OPTICAL PROCESSOR LOOKS FOR PACKAGING FLAWS

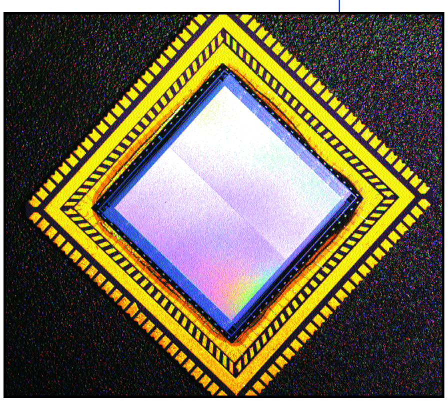
A large food-processing company can suffer hundreds of thousands of dollars in losses each week, owing to such packaging problems as smudged ink on labels and unreadable price codes. Better inspection technology can identify a problem early in the production stage to prevent large batch losses, saving both money and time.

Silicon Mountain Design, Inc. (SMD; Colorado Springs, CO), designed an optical processor that can image products on the assembly line and determine package integrity. The company is working with Teledyne, Inc., to integrate this technology into an optical computing system for industrial inspection. This system can identify faulty packaging, enabling inspectors to remove defective products from the assembly line.

SMD'S HIGH-SPEED CCD-BASED CAMERA WON THE SBIR TECHNOLOGY OF THE YEAR AWARD AT THE 1995 NASA TECHNOLOGY 2005 CONFERENCE.

The technology grew from a BMDO-funded SBIR contract for rapid target recognition and missile detection. SMD's optical processor consists of a camera based on a charge-coupled device (CCD) and a spatial light modulator located on the same chip. This arrangement eliminates a data bottleneck and helps acquire images rapidly. For example, the optical processor can image products in various stages of completion and identify such manufacturing parameters as package integrity and visual appeal.

The optical processor can also be used for medical imaging in combination with computer-aided diagnosis. Historically, human inspection of Pap smears posted false negative results up to 30 percent of the time. SMD's technology can screen a microscope slide and identify the most atypical cells, saving technicians time and quickly routing suspicious slides to an experienced pathologist. This technology can also be used to examine radiographic images or to analyze live fluoroscopic images. SMD projects a prototype within a year.



■ SMD's optical processor, pictured above, consists of a CCD-based camera and a spatial light modulator located on the same chip.

The company is also working with the University of Colorado (Colorado Springs) to develop a solid-state miniaturized imager with a disposable imaging head. This device will give doctors a better view during endoscopic procedures, such as examining patients for esophageal cancer or performing surgery inside the body.

NASA singled out SMD for excellence at the October 1995 NASA Technology 2005 conference, held in Chicago, Illinois. The company received the SBIR Technology of the Year Award for its high-speed CCD-based camera, used for analyzing kinetic weapons and the flight dynamics of missiles.

ABOUT THE TECHNOLOGY

For pattern recognition, the two principal functions are digital image acquisition and image comparison. The first function can be performed by a pixel array detector or a digitizer. A hardware solution for the second function, a spatial light modulator (SLM), can produce a pixel-by-pixel comparison image from two digital inputs.

Parallel process architectures speed both image-processing steps dramatically. Under these conditions, however, the serial data transfer step between the detector and the SLM becomes a bottleneck. SMD used a combination of micromachining technology and ultrathin wafer processing to put a CCD and the SLM on the same chip. The resulting high-speed optical processor performs real-time screening or enhancement of any digital image database.

NEW TOOL PROMISES SMALLER, FASTER COMPUTER CHIPS

The semiconductor industry has targeted ever-smaller circuits in its drive toward faster computer chips that pack more memory into less space. But those miniaturization goals make integrated circuit (IC) manufacturers face a task equivalent to painting a thin line with a thick brush.

In a recent advance, Sandia National Laboratories (SNL; Livermore, CA) and AT&T Bell Laboratories developed a new research tool that produces chips with features below 0.1 microns—three times smaller than today's best feature sizes. IC manufacturers did not expect to achieve this precision until the year 2007. Smaller feature sizes will result in ICs with higher memory density, higher performance capabilities, and lower energy consumption rates.

In a recent test, Sandia printed the world's first working microelectronic device that uses extreme ultraviolet light lithography (EUVL). The device, a field-effect transistor and a common building block of all integrated circuits, features an electrical channel (or gate width) of 0.10 microns—one thousandth the width of a human hair. To further evaluate and develop EUVL technology, the researchers plan to create more complicated devices and circuits.

SNL researchers are also investigating the possibility of using the EUVL tool to print some of the world's smallest holograms. The nanometer-scale holograms could form the basis of a new security system that would use holographic "microtags" to brand everything from computer chips to currency to compact discs. The advantages of the microtag lie in both its size and complexity. Its sub-0.2 micron features make the microtag difficult to find and replicate, frustrating chip counterfeiters who bombard computer integrators with forgeries. Its physical orientation provides another security feature: Only read-out equipment that illuminates the microtag at the correct incidence angles can discover its true identity.

This technology grew out of a BMDO program in which SNL developed a laser plasma source of extreme ultraviolet radiation. BMDO needed this EUVL source, intended for classified studies of detector performance and material survivability at these wavelengths, as an alternative to synchrotrons, which were not approved for classified research.

ABOUT THE TECHNOLOGY

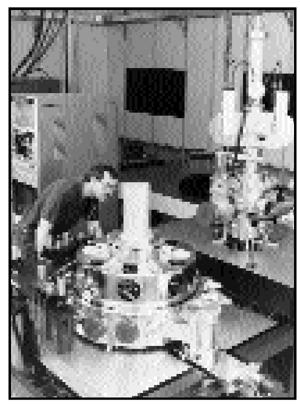
Lithography transfers microscopic device patterns onto silicon wafers, level by level. Shrinking device dimensions continue to push traditional optical lithography systems to the limits of fine resolution between the circuit elements. An EUVL system, using shorter wavelength light than traditional systems, can overcome the optical resolution problems inherent when the device feature size approaches the wavelength of the light used.

SNL's EUVL source uses a laser striking a solid metal target to create a plasma of ions. When these ions lose their energy, they emit a broad spectrum of radiation centered in the extreme ultraviolet region. A monochrometer filters out unwanted light and helps choose the wavelength best suited for a particular application.

Can You Imagine . . .

. . . a chip-making tool that uses extreme ultraviolet light to print lines as small as 0.1 microns, shaving more than two-thirds off current minimum dimensions.

SNL'S RESEARCH TOOL PRODUCES FEATURE SIZES BELOW 0.1 MICRONS, A FEAT OF PRECISION THAT IC MANUFACTURERS DID NOT EXPECT TO ACHIEVE UNTIL 2007.



■ Mechanical technician Yon Perras inspects the extreme ultraviolet light lithography tool, which etches fine patterns in silicon chips.

Can You Imagine . . .

. . . a new processing alternative that treats machine components, altering their surface layers to improve durability and resistance to corrosion.

NEW PROCESS ALTERNATIVE PROMISES HARDER MATERIALS

When manufacturing such heavy machinery as automobiles, hardness and durability are two qualities essential to satisfy quality-seeking consumers. The low-wear requirements of the machines that manufacture these products also make these qualities essential to manufacturers.

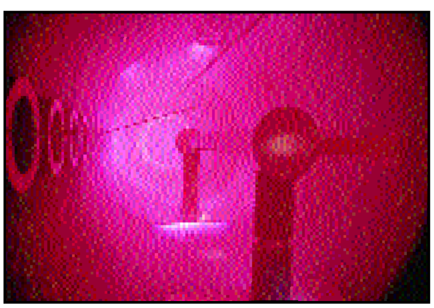
Through an Advanced Technology Program-sponsored project, a consortium of 14 participants is addressing these qualities, scaling up a technology called plasma source ion implantation (PSII). Rather than coating industrial parts, which must be toughened to survive severe environments, PSII actually changes the material surface, providing performance and environmental advantages over other hardening methods. It uses a power modulator derived from BMDO-funded work on the particle beam accelerator developed at Los Alamos National Laboratory (LANL; Los Alamos, NM).

This process can be used to harden components for automobiles, aircraft, power plants, and prosthetics. For example, General Motors is investigating PSII to change the surfaces of lightweight aluminum and magnesium alloys so they can withstand the high wear and harsh environment found in engines. Substituting these materials for steel and iron could result in a 10 percent decrease in the cost of making automotive power trains.

GENERAL MOTORS IS INVESTIGATING PSII TO CHANGE THE SURFACES OF LIGHTWEIGHT ALUMINUM AND MAGNESIUM ALLOYS USED IN ENGINES.

In addition, treating production machine parts themselves increases their service lives for manufacturing, thereby reducing associated costs and downtimes in manufacturing plants. In a study comparing the service lives of steel-tool punches, nitrogen-implanted punches using PSII lasted two times longer than chrome-only plated punches and five times longer than untreated punches. With further development, some dies and tools may last 10 times longer than their untreated counterparts.

The modulator used to control the voltage output from the power source came from the BMDO-funded Ground Test Accelerator project at LANL. Built as a follow-on to the Beam Experiment Aboard Rocket project, the Ground Test Accelerator, a cryogenically cooled device, was developed to provide a model of a space-based neutral particle beam weapon.



■ Rather than coating the material, PSII modifies its surface. Pictured above is a look inside the PSII chamber.

ABOUT THE TECHNOLOGY

In PSII, injecting a low-pressure gas, such as nitrogen, into a steel vacuum chamber hardens the material. The nitrogen ionizes into a plasma using oscillating radio frequency waves, and it strips electrons from the gas atoms. Then, exposing the material to short pulses of negative voltage causes positive-charged ions to accelerate toward the negative-charged material, bombarding it from all sides. The ions penetrate and modify layers of the material near the surface. This process can treat polymer surfaces as well as metals.

The process offers several advantages over other hardening methods. For example, since PSII is not a coating, adhesion and delamination are not concerns. Less expensive and with a higher average current (1.00 ampere versus 0.03 ampere) than line-of-sight implantation processes, it permits much faster implantation. Also, PSII does not require masking or expensive fixtures to manipulate nonplanar parts, and it evenly treats such odd-shaped items as power tools, door locks, and drive trains. An environmentally benign “dry” alternative to the wet chemical baths used in electroplating, the process does not produce effluent pollutants.